APPLICATION FOR UNITED STATES

LETTERS PATENT

METHOD AND APPARATUS FOR DETERMINING CHANNEL CONDITIONS IN A COMMUNICATION SYSTEM

By:

Krishna Balachandran and Sanjiv Nanda

CERTIFICATE OF EXPRESS MAIL

"Express Mail" mailing label number: EL041357300US
Date of Deposit: November 28, 2000
I hereby certify that this paper or fee is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" on the date indicated above and is addressed to: Box Patent Application, Assistant Commissioner for Patents, Washington, D.C. 20231.

Leanora Petrowski

METHOD AND APPARATUS FOR DETERMINING CHANNEL CONDITIONS IN A COMMUNICATION SYSTEM

TECHNICAL FIELD

The invention in one embodiment relates generally to communication networks and, more particularly, to communications over wireless and cellular data networks.

BACKGROUND

With the rapid growth of wireless communications, the industry is developing and implementing a variety of transmission protocols in order to provide faster, more robust and more efficient communications. System performance can be improved by choosing the appropriate symbol rate, modulation and coding scheme and transmit power under the prevailing channel conditions. In order to select the best protocol, the transmitting station must have reliable current knowledge of the prevailing channel conditions at the receiver. Determining the prevailing channel conditions has proven to be computationally complex and susceptible to error. Accordingly, there is a need for a reliable, simple, efficient way to obtain current knowledge of the prevailing channel conditions in a communication link

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of one example of a system;

FIG. 2 is a block diagram of exemplary components for computing symbol error probability in the system of FIG. 1;

FIG. 3 is a block diagram of exemplary components for computing symbol error probability in the system of FIG. 1;

FIG. 4 is a block diagram of an exemplary employment of symbol error probability for selection of modulation and coding schemes, for rate adaptation and power control in the system of Fig. 1;

FIG. 5 is a flow diagram illustrating determination of channel conditions in the system of Fig. 1;

FIG. 6 is a graph showing curves of the mean bit error probability (vertical scale) versus carrier to interference ratio (horizontal scale) computed for different environments and mobile speeds for the system of Fig. 1.

DETAILED DESCRIPTION

Turning to Fig. 1, the system 100 in one example includes a plurality of components such as computer software and/or hardware components. A number of such components can be combined or divided in different configurations. For example, the invention may be implemented employing at least one computer-readable signal-bearing medium. One example of a computer-readable signal-bearing medium comprises an instance of recordable data storage medium 101 such as one or more of a magnetic, optical, biological, and atomic data storage medium. In another example, a computer-readable signal-bearing medium comprises a modulated carrier signal transmitted over a network comprising or coupled with systems over a local area network ("LAN"), the Internet, and a wireless network. An exemplary component of a system employs and/or comprises a series of computer instructions written in or implemented with any of a number of programming languages, as will be appreciated by those skilled in the art.

Referring to FIG 1, in one example, system 100 includes a transmitter 110 which receives data 102 to be transmitted. Data 102 in one example, can be represented as an information bit sequence $\{a_k\}$. Encoder 112 in one example comprises a block encoder or a convolutional encoder. For example, encoder 112 encodes the information bit sequence $\{a_k\}$ to output a coded sequence $\{c_k\}$. An interleaver 114 interleaves the coded sequence $\{c_k\}$. Coded sequence $\{c_k\}$ is then mapped to a symbol sequence by a symbol mapper 116. At symbol mapper 116, each symbol is chosen from an M-ary signal constellation. In other words, the Coded sequence $\{c_k\}$ is transformed into a finite set of M-ary symbols where M corresponds to the number of symbols.

The code rate and symbol mapping are chosen based on channel quality feedback from a receiver in the manner described below. A transmit filter 118 performs pulseshaping to improve waveform characteristics for transmission of the signal over the air or other transmission medium. The resulting signal is transmitted over a fading dispersive channel 120. The signal is also degraded by additive white gaussian noise (AWGN) 121 input to the channel at adder 122.

Receiver 123 receives the transmitted signal the over fading dispersive channel 120. Front end analog receive filter 124 processes the incoming signal from fading dispersive channel 120. Receive filter 124 is matched to operate with transmit filter 118. Sampler 126 periodically samples the output of receive filter 124.

Multipath or time dispersion characteristics can result in inter symbol interference (ISI) that significantly degrades performance. Decision device 128 is typically employed in order to mitigate the effect of ISI. It is possible to use a decision device that provides either *hard* (*e.g.*, binary) outputs corresponding to the received raw symbol sequence or to employ a

decision device that provides *soft* outputs in the form of probabilities or log likelihood ratios. System 100 in one example uses a decision device 128 at the receiver to provide soft outputs.

Soft outputs may be obtained from appropriate decoders or equalizers. For example, minimum Euclidean distance decoders (*e.g.*, Viterbi decoders) can use soft outputs in order to carry out soft decision decoding (*See* J. Hagenauer and P. Hoeher, "A Viterbi Algorithm with Soft Decision Outputs and its Applications," *Proceedings, IEEE Globecom*, 1989 incorporated herein by reference). Examples of equalization techniques that can generate log likelihood ratios include the Bahl-Cocke-Jelinek-Raviv (BCJR) *Maximum a Posteriori* (MAP) algorithm, L. R. Bahl, J. Cocke, F. Jelinek and J. Raviv, "Optimal Decoding of Linear Codes for Minimizing Symbol Error Rate," *IEEE Trans. On Information Theory*, Vol. IT-20, pp. 284-287, March 1974, and the *Soft Output Viterbi Algorithm* (SOVA), J. Hagenauer and P. Hoeher, "A Viterbi Algorithm with Soft Decision Outputs and its Applications," *Proceedings, IEEE Globecom*, 1989, incorporated herein by reference for background purposes.

The soft outputs used in system 100 are obtained from decision device 128 which can be either an equalizer or a demodulator or both. In general, soft outputs represent the likelihood or probability of each received raw symbol being the value that it is assumed to be for decoding operations. For example, in the case of a binary transmission, (M=2), the soft outputs represent the probability of each raw symbol being a '1' (p_1) or a '0' (p_0). In another aspect of system 100, decision device 128 generates a *log likelihood ratio* (i.e., $\log(p_1)-\log(p_0)$) value for each raw symbol.

Regardless of whether log likelihood ratios or probabilities are obtained from decision device 128, the values corresponding to each symbol need to be averaged to obtain an error rate estimate that is representative of channel conditions. Two methods for computing the

mean Symbol Error Probability (SEP) are shown for purposes of illustration. A first method is shown in Figure 2. For each raw symbol, c_k, decision device 228 generates the *a posteriori* probability mass function, $p_1(c_k)$ and $p_0(c_k)$, from the set of observations at the output of the communication channel where

$$p_1(c_k) = \text{Probability}\{c_k = 1 \mid \text{observations at decision device input}\} \text{ and}$$

$$p_0(c_k) = (1 - p_1(c_k)).$$

From p_0 and p_1, processor 230 computes the SEP for c_k as

$$\text{SEP}(c_k) = min[p_0(c_k)\ ,\ p_1(c_k)].$$

Processor 232 then computes the mean SEP or mean symbol error rate estimate as a moving average of symbol error probabilities. Of course, calculating a moving average of symbol error probabilities can be done in a variety of different ways as would be familiar to one of ordinary skill in the art. The mean SEP output from processor 232 is provided as feedback to transmitter 110. Transmitter 110 compares the mean SEP to pre-determined thresholds in order to determine the coding and modulation scheme, signal power, or other communication protocol to use for subsequent transmissions. Alternatively, selection of appropriate coding and modulation schemes, signal power, or other communication protocol can be performed at the receiver 123. In such case, receiver 123 signals transmitter 110 to use the new protocol.

In another example, shown in Figure 3, decision device 328 generates a log likelihood ratio, $r(c_k) = \log(p_1)\text{-}\log(p_0)$. Assuming logarithms to the base e, p_1 and p_0 are computed by using $p_0 = (1 - p_1)$, as follows:

$$p_1(c_k) = 1/(1+\exp(r(c_k))$$

$$p_0(c_k) = 1/(1+\exp(-r(c_k)))$$

From p_0 and p_1, processor 330 computes the symbol error probability (SEP) for c_k as

$$\mathrm{SEP}(c_k) = min[p_0(c_k)\ ,\ p_1(c_k)].$$

Processor 332 then computes the mean SEP as a moving average of the SEPs for each raw symbol. The mean SEP output from processor 332 is then provided as feedback to transmitter 110. As noted with regard to the example of Figure 2, transmitter 110 compares the mean SEP to pre-determined thresholds in order to determine the coding and modulation scheme or other communication protocol to use for subsequent transmissions. FIG. 4 depicts a block diagram of an exemplary communication system employing mean SEP for MCS, rate adaptation and power control.

A flowchart generally illustrating the operation of system 100 is shown in Fig 5. In the method 500, M-ary symbols are received over a communications channel in step 502. A decision device at a communication receiver determines soft decision metrics for each of the M-ary symbols received in step 504. These soft decision metrics may be calculated according to the *a posteriori* probability mass function, $\{p_0, p_1, p_2, \ldots, p_M\}$, as explained above. In Step 506, SEPs are determined for each of the M-ary symbols from the probabilities determined in step 504 using

$$\mathrm{SEP} = 1 - \max(p_0, p_1, p_2, \ldots, p_M).$$

Alternatively, the decision device determines the a posteriori probability mass function, $\{p_0, p_1\}$ for each of the log_2M bits represented by an M-ary symbol received in step 504. In Step 506, the Bit Error Probability (BEP) is computed for each of these bits from the probabilities determined in step 504 using

$\text{BEP} = 1 - \max(p_0, p_1)$.

In order to obtain a good overall error rate estimate, a moving average of the SEPs or BEPs is calculated in step 508. The moving average is fed back to the transmitter in step 510. The transmitter compares the moving average to thresholds in step 512 and determines in step 514 whether any predetermined thresholds for communication protocol changes have been met or exceeded. If a threshold has been met or exceeded, the transmitter selects a new communication protocol in step 516 and informs the receiver of the new protocol in step 518. Alternatively, the receiver can employ the symbol error probability to select a communication protocol and signal the transmitter to implement the new communication protocol. The new protocol is implemented and the process of determining the reliability of the communication channel repeats under the new protocol.

As shown in Figure 4, in addition to MCS selection, virtually any communication protocol that is changed depending on a change in channel conditions can be modified based on SEP or BEP estimates made according to system 100. In general, system 100 will prove useful in information transmission systems where SEP or BEP estimates are used to adjust modulation and coding schemes or other communication protocols in response to changing channel conditions and where soft outputs can be derived from a decision device at the receiver. For example, in addition to selecting the best modulation and coding scheme, system 100 can be used in connection with the adjustment of transmitter power levels and in making handover decisions. System 100 is applicable to both uplink and downlink communications.

Simulations were carried out in order to study the behavior of the mean BEP determined according to system 100. The simulations assume 8-PSK (M=8, i.e., 8 phase shift

keying) modulation, GSM symbol rate, training sequence and burst structure. Both Typical Urban (TU) and Hilly Terrain (HT) channel models are considered and different mobile speeds are assumed.

Figure 6 shows the mean BEP as a function of carrier to interference ratio (C/I) for different environments and mobile speeds. The results indicate that for a fixed delay spread environment (*e.g.*, HT), the mean BEP is invariant across mobile speeds. The mean BEP also shows more degradation as the amount of dispersion increases. This validates the BEP measure derived according to system 100 since it includes the effect of the received signal and interference power as well as other receiver impairments. This behavior is also consistent with the Bit Error Rate performance that would be observed in the uncoded case.

The flow diagrams depicted herein are just exemplary. There may be many variations to these diagrams or the steps or operations described therein without departing from the spirit of the invention. For instance, the steps may be performed in a differing order, or steps may be added, deleted, or modified.

Although exemplary embodiments of the invention have been depicted and described in detail herein, it will be apparent to those skilled in the relevant art that various modifications, additions, substitutions, and the like can be made without departing from the spirit of the invention and these are therefore considered to be within the scope of the invention as defined in the following claims.